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EXCEDE III Calibration Manual

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

A calibration plan for the scanning photometers, 5200/5228 photometers, UV and visible spectrometers, x-ray detectors, ESA, and RPA is developed. Descriptions of the experimental apparatus and procedures are discussed.

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1. INTRODUCTION

This document describes the calibration procedures for the different instruments provided by Visidyne to be flown as part of the EXCEDE III rocketborne payload.

There are a total of fourteen instruments to be calibrated: two spectrometers, eight photometers, two X-ray detectors, one electrostatic analyzer (ESA), and one retarding potential analyzer (RPA). All of these instruments will be calibrated at Visidyne except for a certain portion of the UV spectrometer calibration, which will take place at the AFGL UV Calibration Facility.

The different types of calibration tests are as follows:

a) Absolute calibration
b) Field-of-view response
c) Off-axis rejection
d) Linearity and dynamic range
e) Noise level
f) Scanning linearity
g) Spectral response
h) Wavelength calibration

The appropriate tests to be performed on the optical instruments are listed in Table 1. Additional useful information can be found in the following Visidyne documents:

a) "EXCEDE III Interface Control Document", Visidyne Inc., VI-1079, Burlington, MA, 25 April 1988.
b) "Critical Design Review and Technical Review", Visidyne Inc., VI-1134, Burlington, MA, 15 December 1987.
c) "EXCEDE III Instrumentation Counting Rates", Visidyne Inc., VI-1113, Burlington, MA, 29 April 1988. AFGL-TR-88-0121, ADA207574.
d) "Anticipated Signal Levels for the ESA and RPA", Visidyne, Inc. VI-1264, Burlington, MA, 13 February 1988. AFGL-TR-89-0071.

2. CALIBRATION EQUIPMENT

This section describes the equipment and components needed in the calibration of the Visidyne's EXCEDE III instruments.

2.1 Ground Support Equipment (GSE)

Visidyne's EXCEDE III instruments can be divided into two categories according to the type of data interface. Instruments that reside in the Sensor Module all have a common serial digital interface. Instruments housed in the Gun Module require an analog data interface. This is summarized below.

Instruments	Data Interface
UV Spectrometer	Serial Digital
Visible Spectrometer	Serial Digital
Scanning Photometers	Serial Digital
Boresight Photometers	Serial Digital
Fixed Photometers	Serial Digital
X-Ray Detector	Serial Digital
Retarding Potential Analyzer	Analog
Electrostatic Analyzer	Analog

Because of these two different types of interface, two separate and distinct GSE systems are required.

2.1.1 GSE for Serial Digital Instruments

The GSE for the serial digitally interfaced instruments consists of the following:

a) A GSE "suitcase"

b) An IBM PC/AT computer

c) A digital I/O card for the IBM/PC
(Data Translation, Inc., Model #DT2817)

A block diagram of this GSE is shown in Figure 1. The GSE "suitcase" consists of power supplies which provide the +28 volts bias to the instruments, a Telemetry (T/M) Emulator circuit board (Visidyne Dwg. #102708), and the cabling connecting the GSE to the instrument and to the computer. All of these items are packaged in a small carrying case for easy portability. The GSE's Telemetry Emulator provides the instrument with handshaking signals that mimic the signals provided for in-flight data transfer. The T/M Emulator acquires data from the instrument, performs a serial-to-parallel conversion, and places the data in a sixteen-bit register which is read by a dedicated IBM PC/AT computer via the

DT2817 parallel digital I/O board. The data are stored on the computer's hard disk and are later transferred onto floppy disks for future data analysis and archiving.

A flow diagram of the GSE software is shown in Figure 2. The GSE software operates in a loop which, when engaged, continuously checks the T/M Emulator for new data by reading its status output register and testing for a "Data Ready" flag. When that flag is found to be set, the computer reads the data which are in the T/M Emulator's output register and stores them in RAM. When a sufficient amount of data has been collected, or when the computer runs out of available RAM, the raw data are transferred to the hard disk where it can be accessed for plotting, analysis, and data reduction software routines.

A total of 60 seconds of data can be acquired before being written onto the hard disk, at which point the computer becomes RAM-limited.

2.1.2 The GSE for Analog Instruments

The GSE for the ESA and RPA consists of a simple box which provides the instrument power and the interconnection points to monitor the analog data (with an oscilloscope or similar instrument in real time). Simultaneously, the data are written onto a hard disk where it and can be analyzed and displayed.

2.2 Sources

2.2.1 The Standard of Spectral Irradiance

The standard lamp is a 1000 watt, G.E. type FEL. It is a quartz-halogen lamp with coiled-coil filament and is operated at 7.9 A dc. The absolute accuracy of the output current from the power supply should be 0.25% or better, and should be monitored using an ammeter of comparable accuracy. The spectral irradiance standard has uncertainties relative to SI units of 2.5% from 2500 to 3000 Å and 1% from 3000 to 8000 Å. A plot of the spectral irradiance versus wavelength for this type of lamp is shown in Figure 3.

2.2.2 The Standard Xenon Lamp

This lamp covers the 3000-6500 Å spectral range. It is available at the AFGL UV Calibration Facility.

2.2.3 The Standard Mercury Lamp

This lamp covers the 2000-3000 Å spectral range. It is available at the AFGL UV Calibration Facility.

2.2.4 Carbon Monoxide (4th Positive) Lamp

This lamp covers the 1150-2000 Å spectral range. It is available at the AFGL UV Calibration Facility.

2.2.5 Uncalibrated Tungsten Lamp

This lamp is available at Visidyne. The lamp has a coil-coil 1000 watt filament with a quartz-halogen envelope. A power supply to operate the lamp is also available at Visidyne and has a shunt resistor calibrated to better than $\pm$ 0.25 percent.

2.2.6 Laser Source

The Helium-Neon 8 mW laser, Uniphase Model 1201-1, and its power supply, is available at Visidyne.

2.2.7 X-Ray Sources

X-ray lines with energies between 1 and 6 keV are used in the energy calibration of the proportional counters, and are obtained from an X-Kit and a Fe-55 radioactive source. The X-Kit is manufactured by Isotope Products Laboratories, Burbank, CA. It consists of a 1 mCi Cm-244 sealed source, a holder, and six targets, each producing one single characteristic X-ray line, with energies between 0.523 and 4.97 keV. Since the beryllium windows of the proportional counters have a cut-off energy of 1 keV, only targets which produce X-rays with energies greater than 1 keV are used. They are magnesium, aluminum, polyvinyl chloride, and titanium. Listed below are the different target materials to be used in the production of the desired X-rays, together with their respective energies.

Target Material	Principal Energy (keV)
Magnesium	1.254
Aluminum	1.487
Polyvinyl Chloride	2.622
Titanium	4.97

The Fe-55 source provides the 5.898 keV line.

2.3 Optical Components and Accessories

2.3.1 The Diffuse Reflectance Standard Screen

The diffuse reflectance standard screen is a screen painted with Eastman White Reflectance Paint. This paint is a composition of specially purified

barium sulfate which provides unsurpassed diffuse reflectance of radiant energy in the region from 2000 Å to 2.5 μm. This paint is very stable in time, and only small changes in reflectance are observed when a surface coated with this paint is exposed to high intensity UV radiation for extended periods. Figure 4 shows the percent reflectance of the screen compared to smoked magnesium oxide as a function of incident wavelength.

2.3.2 Light Collimator System

This system consists of a focused radiation source together with a light collimator. A diagram of this system, as it would be used in the field-of-view mapping of an instrument, is shown in Figure 6. The focused radiation source consists of the uncalibrated tungsten lamp, the magnesium fluoride lens, and an enclosure. The light collimator is an on-axis type consisting of a 12-1/2 inch diameter parabolic mirror with a focal length of approximately 75 inches and a one inch effective diameter diagonal mirror. The two optical surfaces are coated with $Al\text{-}MgF_2$.

2.3.3 Magnesium Fluoride Lens

The magnesium fluoride lens has a 1-1/2 inch diameter and a focal length of three inches. It is usable from 110 nm to 7.5 μm.

2.3.4 Neutral Density Filters

A set of neutral density filters of assorted optical densities is available at Visidyne.

2.3.5 Rotary Table

The rotary table used in the field-of-view mapping of the optical instruments consists of two high resolution rotation stages. Each stage provides an angular motion over 16 degrees of fine adjustment travel, with a resolution of six arc-sec. The backlash is maintained below three arc-sec, and the repeatability is of the order of three arc-sec. The load capacity is 100 lb (45 kg). The two rotation stages are held orthogonally to each other by an adjustable right-angle fixture. This fixture allows positioning of the orthogonal axes of rotation to intersect at the optical center of the focusing lens of each of the instruments being tested.

2.3.6 Precision Pulser

The pulser is a BNC Model BH-1, available at Visidyne.

2.4 Facilities

2.4.1 Visidyne Vacuum System

A vacuum system, which is owned by Visidyne, will be used. An insulating platform is required to support the experimental package. An extension tube, to accommodate the X-ray sources, will be built.

2.4.2 The AFGL UV Calibration Facility

A schematic of the AFGL UV calibration facility is shown in Figure 5.

3. SCANNING PHOTOMETERS

3.1 Preparation

The following equipment is needed for calibrating the scanning photometers:

a. The EXCEDE GSE.
b. The experimental package.
c. A standard of spectral irradiance.
d. An uncalibrated tungsten lamp.
e. Diffuse reflectance standard screen.
f. Laser source (in the visible spectrum).
g. Rotary table, with angular encoder.
h. Parallel light collimator system.
i. Neutral density filters, assorted.

The experimental data, which consists of the output from the four photometers, housekeeping information, and scan encoder data, will be inputted into the GSE for storage and off-line data analysis.

PRECEDING EACH MEASUREMENT, THE POWER TO THE EXPERIMENTAL PACKAGE TO THE GSE, AND TO ALL THE PERIPHERAL INSTRUMENTATION SHOULD BE TURNED "ON" FOR APPROXIMATELY TEN MINUTES TO STABILIZE THEIR OPERATION.

WHEN USING THE STANDARD OF SPECTRAL IRRADIANCE OR THE UNCALIBRATED TUNGSTEN LAMP, APPROPRIATE EYE PROTECTION SHOULD BE WORN.

3.2 Absolute Calibration

This procedure will lead to a measurement of the single parameter, ϵ_{abs}, which relates the instrument output to the absolute number of photons entering the front aperture of the instrument. The determination of the number of photons is outlined in Table 2.

3.2.1 Test Setup

Figure 7 shows the radiometric calibration geometry. The standard spectral irradiance lamp is placed facing the high reflectance diffusing screen at the required distance and positioned orthogonally to the screen surface. The instrument package is placed adjacent to the source so that its optical axis is as perpendicular to the screen as possible. The instrument package is shielded from any direct radiation from the standard lamp by an opaque screen. The photometers' fields-of-view are filled with the irradiated screen.

The whole assembly shall be located in the laboratory such that the distance to the nearest wall is large compared to the reference distance. The radiation intensity is controlled by varying the distance from the standard lamp to the diffusing screen. For each of the four photometers, calculations show that the lamp can be located at the standard distance of 50 cm.

3.2.2 Data Taking

The standard of spectral irradiance is turned "ON" and allowed to stabilize (for a time TBD). The current through the lamp is set at the manufacturer's recommended value.

With the rotating mirrors stopped at their "zero" positions, the four digital data outputs corresponding to the four detectors are recorded by the GSE and stored. Approximately ten data sets spaced evenly in time will be recorded.

3.3 Noise Level

The noise level of the instrument is measured with the front aperture of the instrument covered with an appropriate light-tight cover and with the room in total darkness. Under these conditions, the digital output of the four detectors are recorded by the GSE and stored. Several readings of the noise level, over a one-hour interval, shall be recorded. The noise level is a single parameter in units of photoelectrons/second. Additional data will be obtained during flight. Care will be taken to suppress any stray light sources in the room.

3.4 Linearity and Dynamic Range

This test determines the dynamic range of each photometer and the range over which their responses are linear. The result from this test will be four curves of the incident luminous flux versus instrument counting rates and will be referred to as the function $I(N_{det})$.

3.4.1 Test Setup

The instrument is directed facing an uncalibrated tungsten filament lamp two or three meters away, as shown in Figure 8. The current through the lamp is increased until saturation or near saturation of the outputs of the PMT's occurs. Time will be allowed for the lamp to stabilize.

3.4.2 Data Taking

Under the above conditions, the outputs from the detectors are recorded. Without changing the current through the lamp, neutral density filters of various optical densities are placed in front of the light source, and the different outputs of the PMT's corresponding to the known absorption are recorded.

Since the lamp intensity can drift, it is important to check its stability as the series of measurements progresses. To monitor the stability of the lamp, an intensity normalization point shall be chosen in the linear portion of the response curve of the instrument. This intensity is obtained by interposing a fixed amount of absorption in the light beam. Following each recorded data point, and before more absorption is introduced in the beam, the intensity of the lamp shall be checked at the normalization point and adjusted if necessary. This procedure is repeated until the noise levels of the photometers are reached.

If the entire dynamic range of the instrument cannot be covered with the previous lamp setting and using all the available filters, the intensity of the lamp shall be reduced to the intensity used to normalize the different measurements but without the filters. With this new lamp intensity, the original data taking procedure is repeated until the noise level of the system is reached.

The above procedure will produce only a relative measurement of the incident flux. These data are converted to absolute numbers by relating the detector output from the absolute calibration measurement to the corresponding output measured here.

3.5 Spectral Response

The spectral responses of the four filters in the instrument cannot be measured in-house. Instead the manufacturer's calibration curves will be used; these curves are referred to as $T(\lambda)$. If possible, the filters' response will be remeasured following the experiment flight.

3.6 Spatial Scan Linearity

This test calibrates the potentiometer which encodes the angular displacement of the rotating mirrors. It relates the scanning angle to the potentiometer voltage.

The experiment is setup approximately three meters from a blank wall. The beam of a laser impinges on the scanning mirror and is reflected on the wall of the laboratory for different potentiometer voltages. The positions of the laser beamspot on the wall are noted and their separation measured. The corresponding potentiometer readings are recorded and from these data the relation $\Theta(V_{p\cdot t})$ is determined.

3.7 Field-of-View Mapping

This test measures the instrument response as a function of the angle of the incident light. All angles will be measured with respect to the instrument optical axis. The results of this test will be $g(\Theta,\phi)$, the incident light intensity versus angular displacement. Since the apertures of the photometers are circular, their angular responses are only a function of Θ and need only be mapped in one scanning direction (horizontal).

3.7.1 Test Setup

The experimental setup is shown in Figure 6. The instrument is positioned on a rotary table. The intersection of the axes of rotation are made to coincide with each of the optical centers of the focusing lenses of the photometers. The instrument rotating mirror is positioned at its "zero" angular position.

An uncalibrated tungsten light source is positioned as shown in the figure, so that its image is focused by a converging lens at the focal point of an parabolic mirror. The photometer is located in the beam of parallel rays from the source. Care must be taken that the entire aperture of the instrument is always filled by the light from the source.

The instrument is rotated in the vertical direction to determine the position of the horizontal plane of symmetry of the aperture (the angular steps TBD). The output from the detector is recorded and from these data, the centroid of the angular response in the vertical direction is determined. This insures that the source and the horizontal plane of symmetry of the entrance aperture are coplanar.

3.7.2 Data Taking

The instrument is rotated in the horizontal plane so that the output signal is close to or at the instrument noise level, and the corresponding angular position recorded. The angular position of the instrument is then changed in steps, past the zero angular reference, until the output signal is again near or at the instrument noise level. This angular span is divided in a number of equal angular intervals (TBD depending on the nominal angular size of the aperture). At each of these angular positions, the output signal amplitude is recorded. To eliminate the backlash of the rotating table, the direction of rotation should always be in the same direction.

The above procedures for setting up and taking data are repeated for each of the four photometers.

3.8 Off-Axis Rejection

This test measures the off-axis light rejection of each photometer. It yields the four response curves of the photometers outside of their fields-of-view to the incident light as they are rotated away from the source of radiation.

3.8.1 Test Setup

The experimental setup is shown in Figure 8. The instrument is positioned on a rotary table and its orthogonal axis of rotation positioned to intersect successively with each of the optical centers of the focusing lenses of the photometers. The rotating mirror is positioned at its "zero" angular displacement position. An uncalibrated tungsten light source is positioned as shown in the figure facing the front aperture of one of the photometer some three to four meters away. Several neutral density filters are positioned in front of this light source.

The whole assembly shall be located in the laboratory such that the distance to the nearest wall is large compared to the source-detector separation.

To improve the sensitivity of the measurements, as the output signal approach the noise level of the instrument, a light chopper positioned near the source shall be used in the light beam.

The instrument is rotated in the vertical and horizontal directions in front of the light source to determine the position of the optical axis of the photometer which must be coplanar with the light source (the angular steps TBD). From these data, the centroids of the angular responses in both directions are determined with their intersection thus determining the instrument optical axis; this is the "zero" angular displacement reference point.

3.8.2 Data Taking

The instrument is rotated in the horizontal plane until the signal out is close to or at the photometer noise level. The angular position at this extreme is recorded as are the signal output levels at several intermediate angular positions.

The first of the neutral density filters is removed. The instrument is rotated further, in 1/2-degree steps and in the same direction until once more the output signal level reaches the noise level of the system. At each angular position, the signal output level is recorded.

The second neutral filter is removed, and the preceding procedure repeated until there are no more filters. The data points, output signal versus off-axis angle, are then plotted using the multiplying factors of the neutral density filters where required.

The above procedures for setting up and taking data are repeated for each of the four photometers.

As a minimum it is necessary to measure in only one direction because of the circular symmetry of the apertures, and optics.

4. 5200/5228 PHOTOMETERS

4.1 Preparation

The calibration procedures for the 5200Å and 5228Å Fixed Photometers are identical. The following equipment is needed:

a. The EXCEDE GSE.

b. The experimental package.

c. A standard of spectral irradiance.

d. An uncalibrated tungsten ribbon lamp.

e. A diffuse reflectance standard screen.

f. A rotary table, with angular encoder.

g. A parallel light collimator system.

h. Neutral density filters, ND1.

The data output of the experiment, which consists of one photometric channel, will be inputted into the GSE for storage and off-line data analysis.

PRECEDING EACH TEST, THE POWER TO THE EXPERIMENTAL PACKAGE, TO THE GSE, AND TO ALL THE PERIPHERAL INSTRUMENTATION SHOULD BE TURNED "ON" FOR APPROXIMATELY TEN MINUTES TO STABILIZE THEIR OPERATION.

WHEN USING THE STANDARD OF SPECTRAL IRRADIANCE OR THE UNCALIBRATED TUNGSTEN LAMP, APPROPRIATE EYE PROTECTION SHOULD BE WORN.

4.2 Absolute Calibration

This procedure will lead to a measurement of the single parameter, ε_{abs}, which relates the instrument output to the absolute number of photons entering the front aperture of the instrument.

4.2.1 Test Setup

Figure 7 shows the radiometric calibration geometry. The standard spectral irradiance lamp is placed facing the high reflectance diffusing screen at the required distance and positioned orthogonally to the screen surface. The instrument package is placed adjacent to the source so that its optical axis is as perpendicular to the screen as possible. The instrument package is shielded from any direct radiation from the standard lamp by an opaque screen. The photometer's field-of-view is filled with the irradiated screen.

The whole assembly shall be located in the laboratory such that the distance to the nearest wall is large compared to the reference distance. The radiation intensity is controlled by varying the distance from the standard lamp to the diffusing screen.

For each photometer, calculations show that the instrument cannot be located at the standard distance of 50 cm. Instead, the lamp should be located approximately five meters away from the screen; in addition, a neutral density filter, ND1, should be placed in front of the lamp. Under these conditions, the

light flux from the standard will be cut down by three orders of magnitude, and the instrument signal is estimated to be ~ 1.3×10^6 photoelectrons/s. The saturation point is 4×10^6 photoelectrons/s.

4.2.2 Data Taking

The standard of spectral irradiance is turned "ON" and allowed to stabilize (for a time TBD). The current through the lamp is set at the manufacturer's recommended value.

The output signal level of the instrument is recorded. Approximately ten values of the output, spaced evenly in time over a period of ten minutes, shall be recorded.

4.3 Noise Level

The noise level of the instrument is measured with the front aperture of the instrument covered with an appropriate light-tight cover, and with the room in total darkness. Under these conditions, the digital output of the detector is recorded by the GSE and stored. Several readings of the noise level, over a one-hour interval, shall be recorded. Care should be taken to suppress any stray light sources in the room.

4.4 Linearity and Dynamic Range

This test determines the dynamic range of each photometer and the range over which the response is linear. The result from the test is a curve of the luminous flux entering each system versus the instrument counting rate and will be referred to as the function, $I(N_{det})$.

4.4.1 Test Setup

The instrument is directed facing an uncalibrated tungsten filament lamp two or three meters away, as shown in Figure 8. The current through the lamp is increased until saturation, or near saturation of the output of the PMT occurs. Time should be allowed for the lamp to stabilize.

4.4.2 Data Taking

Under the above conditions, the output from the instrument is recorded. Without changing the current through the lamp, neutral density filters of various optical densities, are placed in front of the light source, and the different outputs of the PMT corresponding to the known absorption are recorded.

Since the lamp intensity can drift, it is important to check its stability as the series of measurements progresses. To monitor the stability of the lamp,

an intensity normalization point shall be chosen in the linear portion of the response curve of the instrument. This intensity is obtained by interposing a fixed amount of absorption in the light beam. Following each recorded data point, and before more absorption is introduced in the beam, the intensity of the lamp shall be checked at the normalization point and adjusted if necessary. This procedure is repeated until the noise level of the instrument is reached, and the desired curve is obtained.

If the entire dynamic range of the instrument cannot be covered with the previous lamp setting and by using all the availability filters, the following procedure shall be used. The intensity of the lamp shall be reduced to the intensity used to normalize the different measurements, but without the filters. With this new lamp intensity, the original data taking procedure is repeated, until the noise level of the system is reached.

The above procedure will produce only a relative measurement of the incident flux. These data are converted to absolute numbers by relating the detectors output from the absolute calibration measurement to be corresponding output measured here.

4.5 Spectral Response

The spectral response of the four filters in the instrument cannot be measured in-house. Instead, the manufacturer's calibration curve shall be used; these curves are referred to as $T(\lambda)$. If possible, the filters' response will be remeasured following the experiment flight.

4.6 Field-of-View Mapping

This test measures the instrument response as a function of the angle of the incident light. All angles will be measured with respect to the instrument optical axis. The results of this test will be $g(\Theta,\phi)$, the response as a function of angle. Since the apertures of the photometers are circular, their angular responses are only a function of Θ and need only be mapped in one scanning direction (horizontal).

4.6.1 Test Setup

The experimental setup is shown in Figure 6. The instrument is positioned on a rotary table. The intersection of its orthogonal axes of rotation are made

to coincide, in turn, with each of the optical centers of the focusing lenses of the photometers. The instrument rotating mirror is positioned at its "zero" angular position.

An uncalibrated tungsten light source is positioned as shown in the figure, so that its image is focused by a converging lens at the focal point of a parabolic mirror. The instrument is located in the beam of parallel rays from the source. Care must be taken that the entire aperture of the instrument is always filled by the light from the source.

The instrument is rotated in the parallel light beam, in the vertical direction, to determine the position of the horizontal plane of the symmetry of the aperture (the angular steps TBD). From these data, the centroid of the angular response in the vertical direction is determined. This insures that the source and the horizontal plane of symmetry of the entrance aperture are coplanar.

4.6.2 Data Taking

The instrument is now rotated in the horizontal plane until the output signal is close to or at the instrument noise level. The angular position of the instrument and its output reading at this extreme are recorded. From this point, the angular position of the instrument is then changed in one-tenth degree steps and the corresponding instrument output readings recorded. Data are taken at the successive angular positions until the output signal is again near or at the instrument noise level. To eliminate the backlash of the rotating table, the direction of rotation should always be in the same direction.

4.7 Off-Axis Rejection

This test measures the off-axis light rejection of the instrument. It yields a curve of the instrument response to incident light outside of its field-of-view as it is rotated away from the source of radiation.

4.7.1 Test Setup

The experimental setup is shown in Figure 8. The instrument is positioned on a rotary table with its orthogonal axes of rotation intersecting at the optical center of the focusing lens of the instrument. An uncalibrated tungsten light source is positioned as shown in the figure, facing the front aperture of the instrument some three or four meters away. Several ND1 neutral density filters are positioned in front of this light source.

The whole assembly shall be located in the laboratory such that the distance to the nearest wall is large compared to the source-detector separation.

To improve the sensitivity of the measurements, as the output signal approach the noise level of the instrument, a light chopper located near the source shall be used in the light beam.

The instrument is rotated in the vertical and horizontal directions in front of the light source to determine the position of the optical axis of the instrument which must be coplanar with the light source (the angular steps TBD). From these data, the centroids of the angular responses in both directions are determined with their intersection thus determining the instrument optical axis; this is the "zero" angular displacement reference point.

4.7.2 Data Taking

The instrument is rotated in the horizontal plane until the signal out is close to or at the instrument noise level. The angular position of the instrument at this extreme is recorded as are signal output levels at several intermediate angular positions.

The first of the neutral density filters is removed. The instrument is rotated further, in 1/2-degree steps and in the same direction, until once more the output signal level reaches the noise level of the system. At each angular position, the signal output level is recorded.

The second neutral filter is removed, and the preceding procedure repeated until there are no more filters. The data points, output signal versus off-axis angle, are then plotted using the multiplying factors of the neutral density filters where required.

As a minimum it is necessary to measure in only one direction because of the circular symmetry of the aperture and optics.

5. BORESIGHT PHOTOMETERS

5.1 Preparation

There are two Boresight Photometers to be calibrated. The following equipment is needed:

a. The EXCEDE GSE.

b. The experimental package.

c. A standard of spectral irradiance.

d. An uncalibrated tungsten lamp.

e. Rotary table, with angular encoder.

f. Parallel light collimation system.

g. Diffuse reflectance standard screen.

The data output of the experiment, which consists of one photometric channel, will be inputted into the GSE for storage and off-line data analysis.

PRECEDING EACH TEST, THE POWER TO THE EXPERIMENTAL PACKAGE, TO THE GSE, AND TO ALL THE PERIPHERAL INSTRUMENTATION SHOULD BE TURNED "ON" FOR APPROXIMATELY TEN MINUTES TO STABILIZE THEIR OPERATION.

WHEN USING THE STANDARD OF SPECTRAL IRRADIANCE OR THE UNCALIBRATED TUNGSTEN LAMP, APPROPRIATE EYE PROTECTION SHOULD BE WORN.

5.2 Absolute Calibration

This procedure will lead to a measurement of the single parameter, ε_{abs}, which relates the instrument output to the absolute number of photons entering the front aperature of the instrument.

5.2.1 Test Setup

Figure 7 shows the radiometric calibration geometry. The standard spectral irradiance lamp is placed facing the high reflectance diffusing screen at the required distance and positioned orthogonally to the screen surface. The instrument package is placed adjacent to the source, such that its optical axis is as perpendicular to the screen as possible. The instrument package is shielded from any direct radiation from the standard lamp by an opaque screen. The photometer's field-of-view is filled with the irradiated screen.

The whole assembly shall be located in the laboratory such that the distance to the nearest wall is large compared to the reference distance. The radiation intensity is controlled by varying the distance from the standard lamp to the diffusing screen. Calculations show that each instrument can be calibrated simultaneously with its corresponding spectrometer. Specifically, each spectrometer should be located from the screen at a distance ten times the standard distance, or 5 m. It may be necessary to use a neutral density filter to further reduce the flux into the aperture of the instrument. If this filter is needed, it should be located as close to the lamp as possible, but, far enough away so as not to be damaged by the heat generated by the lamp.

5.2.2 Data Taking

The standard of spectral irradiance lamp is turned "ON" and allowed to stabilize (for a time TBD). The current through the lamp is set at the manufacturer's recommended value. The output of the instrument is recorded. Approximately ten values of the output, spaced evenly in time over a period of ten minutes, shall be recorded.

5.3 Noise Level

The noise level of the instrument is measured with the front aperture of the instrument covered with an appropriate light-tight cover and with the room in total darkness. Under these conditions, the digital output of the detector is recorded by the GSE and stored. Several readings of the noise level over a one-hour interval shall be recorded. The noise level is a single parameter in units of photoelectrons/second. Care should be taken to suppress any stray light sources in the room.

5.4 Linearity and Dynamic Range

This test determines the dynamic range of the instrument and the range over which its response is linear. The result from this test will be a curve of the luminous flux entering the system versus instrument counting rate and will be referred to as $I(N_{det})$.

5.4.1 Test Setup

The instrument is directed facing an uncalibrated tungsten filament lamp two or three meters away, as shown in Figure 8. The current through the lamp is increased until saturation, or near saturation, the output of the PMT occurs. Time should be allowed for the lamp to stabilize.

5.4.2 Data Taking

Under the above conditions, the output from the instrument is recorded. Without changing the current through the lamp, neutral density filters of various optical densities, are placed, in front of the light source, and the different outputs of the PMT corresponding to the known absorption are recorded.

Since the lamp intensity can drift, it is important to check its stability as the series of measurements progresses. To monitor the stability of the lamp, an intensity normalization point shall be chosen in the linear portion of the response curve of the instrument. This intensity is obtained by interposing a fixed amount of absorption in the light beam. Following each recorded data

point, and before more absorption is introduced in the beam, the intensity of the lamp shall be checked at the normalization point and adjusted if necessary. This procedure is repeated until the noise level of the instrument is reached, and the desired curve is obtained.

If the entire dynamic range of the instrument cannot be covered with the previous lamp setting and using all the availability filters, the following procedure shall be used. The intensity of the lamp shall be reduced to the intensity used to normalize the different measurements, but without the filters. With this new lamp intensity, the original data taking procedure is repeated, until the noise level of the system is reached.

The above procedure will produce only a relative measurement of the incident flux. These data are converted to absolute numbers by relating the detector output from the absolute calibration measurement to the corresponding output measured here.

5.5 Spectral Response

The spectral response of the filter in the instrument cannot be measured in-house. Instead the manufacturer's calibration curve shall be used; these curves are referred to as $T(\lambda)$. If possible, the filters' response will be remeasured following the experimental flight.

5.6 Field-of-View Mapping

This test measures the instrument response as a function of the angle of the incident light. All angles will be measured with respect to the instrument optical axis. The resulting data will be displayed as a plot of the incident light intensity versus angular displacement, both in the horizontal and vertical directions.

5.6.1 Test Setup

The experimental setup is shown in Figure 6. The instrument is positioned on a rotary table. The intersection of the axes of rotation are made to coincide with each of the optical centers of the focusing lenses of the photometers. The instrument rotating mirror is positioned at its "zero" angular position.

An uncalibrated tungsten light source is positioned as shown in the figure, so that its image is focused by a converging lens at the focal point of an

parabolic mirror. The photometer is located in the beam of parallel rays from the source. Care must be taken that the entire aperture of the instrument is always filled by the light from the source.

The instrument is rotated in the parallel light beam, in the horizontal plane so that a maximum output signal is generated. This is the "zero" angular displacement reference. The instrument is rotated until the output signal is close to or at the instrument noise level. The angular position of the instrument at this extreme is recorded. The instrument is then rotated toward the zero angular reference, and pass this point, until the output signal is again near, or at the instrument noise level. This angular span is divided in a number of equal angular intervals (TBD, depending on the nominal angular size of the aperture).

5.6.2 Data Taking

At each of these angular positions, the output signal amplitude is recorded. To eliminate the backlash of the rotating table, the direction of rotation should always be in the same direction.

The preceding procedure is repeated, after each horizontal scan the spectrometer is rotated one degree in the vertical direction, until the source image is off the entrance slit.

The spectrometer is rotated in the opposite vertical direction, past the angular orginal position, by an amount equal to the nominal field-of-view. Starting from this new position in elevation, the angular scans are performed, each time after having changed the elevation of the optical axis of the instrument by one degree toward the original position.

6. VISIBLE SPECTROMETER

6.1 Preparation

The following equipment is needed:

a. The EXCEDE GSE.
b. The experimental package.
c. A standard of spectral irradiance.
d. An uncalibrated tungsten lamp.
e. Diffuse reflectance standard screen.
f. Rotary table, with angular encoder.

g. Parallel light collimator system.

h. Neutral density filters, assorted.

i. Rare gas calibration lamps and power supply.

The two digital data outputs of the experiment, the visible flux and the wavelength encoder, will be inputted into the GSE for storage and off-line data analysis.

PRECEDING EACH MEASUREMENT, THE POWER TO THE EXPERIMENTAL PACKAGE, TO THE GSE, AND TO ALL THE PERIPHERAL INSTRUMENTATION SHOULD BE TURNED "ON" FOR APPROXIMATELY TEN MINUTES TO STABILIZE THEIR OPERATION.

WHEN USING THE STANDARD OF SPECTRAL IRRADIANCE OR THE TUNGSTEN LAMP, APPROPRIATE EYE PROTECTION SHOULD BE WORN.

6.2 Absolute Calibration

This procedure will lead to a measurement of the parameter, $\varepsilon_{abs}(\lambda)$, which relates the instrument output to the absolute number of photons entering the front aperture of the instrument. Measurement of $\varepsilon_{abs}(\lambda)$ will be made with and without the attenuation filter.

6.2.1 Test Setup

Figure 7 shows the radiometric calibration geometry. The standard spectral irradiance lamp is placed, facing the high reflectance diffusing screen at the required distance and positioned orthogonally to the screen surface. The instrument package is placed adjacent to the source so that its optical axis is as perpendicular to the screen as possible. The instrument package is shielded from any direct radiation from the standard lamp by an opaque screen. The spectrometer's field-of-view is filled with the irradiated screen.

The whole assembly shall be located in the laboratory such that the distance to the nearest wall is large compared to the reference distance. The radiation intensity is controlled by varying the distance from the standard lamp to the diffusing screen. Calculations show that the spectrometer should be located from the screen at a distance ten times the standard distance, or 5 m. It may be necessary to use a neutral density filter to further reduce the flux into the aperture of the instrument. If this filter is needed, it should be located as close to the lamp as possible, but, far enough away so as not to be damaged by the heat generated by the lamp.

6.2.2 Data Taking

The standard of spectral irradiance is turned "ON" and allowed to stabilize (for a time TBD). The current through the lamp is set at the manufacturer's recommended value. The spectrometer is turned "ON" and the grating mirror encoder and output of the spectrometer are recorded by the GSE and stored. The measurement shall be conducted over a ten-minute time period. During that time, approximately ten data sets, spaced evenly in time, shall be recorded.

6.3 Noise Level

The noise level of the instrument is measured with the front aperture of the instrument covered with an appropriate light-tight cover and with the room in total darkness. Under these conditions, the digital output from the detector is recorded by the GSE and stored. Several readings of the noise level, over a one-hour interval, shall be recorded. Additional measurements will be obtained during flight. Care will be taken to suppress any stray light sources in the room.

6.4 Linearity and Dynamic Range

The purpose of this test is to determine the dynamic range of the instrument and the range over which its response is linear. We assume the linearity and dynamic range are wavelength independent and the measurement will be made at a single wavelength. The result from this test will be a curve of the incident luminous flux versus the instrument counting rate and will be referred to as the function $I(N_{det})$.

6.4.1 Test Setup

The instrument is directed facing an uncalibrated tungsten filament lamp two or three meters away, as shown in Figure 8. The current through the lamp is increased until saturation or near saturation of the output of the PMT occurs. Time will be allowed for the lamp to stabilize.

6.4.2 Data Taking

Under the above conditions, the output from the instrument is recorded. Without changing the current through the lamp, several (as many as ten) neutral density filters of various optical densities are placed in front of the light source, and the different outputs of the PMT corresponding to the known absorption are recorded.

Since the lamp intensity can drift, it is important to check its stability as the series of measurements progresses. To infer the stability of the lamp,

an intensity normalization point shall be chosen in the linear portion of the response curve of the instrument. This intensity is obtained by interposing a fixed amount of absorption in the light beam. Following each recorded data point, and before more absorption is introduced in the beam, the intensity of the lamp shall be checked at the normalization point and adjusted if necessary. This procedure is repeated until the noise level of the instrument is reached, and the desired curve is obtained.

If the entire dynamic range of the instrument cannot be covered with the previous lamp setting and using all the availability filters, the intensity of the lamp shall be reduced to the intensity used to normalize the different measurements, but without the filters. With this new lamp intensity, the original data taking procedure is repeated, until the noise level of the system is reached.

The above procedure will produce only a relative measurement of the incident flux. These data are converted to absolute numbers by relating the detector output from the absolute calibration measurement to the corresponding output measured here.

6.5 Wavelength Calibration and Scan Linearity

The wavelength calibration of the visible spectrometer will be performed using up to five rare gas calibration lamps. These lamps will be powered by a high-frequency, square-wave power supply designed for calibration equipment. The five rare gas lamps are filled with Hg(Ne), Xe, Kr, Ar, and Ne, respectively. Each source has strong well known emission lines which will be used to fit the wavelengths with their respective encoder positions. Table 3 is a list of the emission lines from the different sources. The power supply frequency is 25 kHz, which is much higher than the sampling frequency (750 Hz), and reduces oscillations in intensity due to the lamp power supply. The power supply current is subject to variations of 0.1 percent.

The encoder signal, which is proportional to the angular displacement of the spectrometer grating, is recorded concurrently with the spectral response from the lamps. The encoder position will be plotted versus sample number and fit to a polynomial; the result is expected to be linear. The constants derived from the encoder calibration are combined with the fit of the emission line wavelengths versus sample number resulting in the relationship between the wavelength and the encoder position.

In addition to fitting the wavelength, the peak shape of the emission lines will be fit to determine the resolution of the instrument. The spectrometer has a built-in low pressure Hg(Ne) lamp which will be used to monitor the positions and shapes of a few strong emission lines after the instrument has been calibrated.

As part of the spectral response measurement, the attenuator disk efficiency will be obtained. This efficiency will be calculated by measuring the attenuation of the different lines emitted by the calibration lamps as a disk rotates in front of the entrance slit.

6.6 Field-of-View Mapping

This test measures the instrument response as a function of the angle of the incident light for at least two wavelengths. All angles are measured with respect to the instrument optical axis. The resulting data will be displayed as a plot of the incident light intensity versus angular displacement, both in the horizontal and vertical directions.

6.6.1 Experimental Setup

The experimental setup is shown in Figure 6. The instrument is positioned on a rotary table. The intersection of the axes of rotation are made to coincide with each of the optical centers of the focusing lenses of the spectrometer. The instrument rotating mirror is positioned at its "zero" angular position.

An uncalibrated tungsten light source is positioned as shown in the figure, so that its image is focused by a converging lens at the focal point of a parabolic mirror. The instrument is located in the beam of parallel rays from the source. Care must be taken that the entire aperture of the instrument be filled by the light from the source.

The instrument is rotated in the parallel light beam, in the horizontal plane so that a maximum output signal is generated. This is the "zero" angular displacement reference. The instrument is rotated until the output signal is close to or at the instrument noise level. The angular position of the instrument at this extreme is recorded. The instrument is then rotated toward the zero angular reference, and past this point, until the output signal is again near, or at the instrument noise level. This angular span is divided into a number of angular intervals. (TBD, depending on the nominal angular size of the aperture). Special attention will be paid to the edges of the FOV. The tails of the FOV will be mapped in enough detail to indicate the off-axis rejection.

6.6.2 Data Taking

At each of these angular positions, the output signal amplitude is recorded. To eliminate the backlash of the rotating table, the direction of rotation should always be in the same direction.

The preceding procedure is repeated, after each horizontal scan the spectrometer is rotated one degree in the vertical direction, until the source image is off the entrance slit.

The spectrometer is the rotated in the opposite vertical direction, past the angular original position, by an amount equal to the nominal field-of-view. Starting from this new position in elevation, the angular scans are performed, each time after having changed the elevation of the optical axis of the instrument by one degree toward the original position.

7. UV SPECTROMETER

7.1 Preparation

The following equipment is needed:

a. The EXCEDE GSE.
b. The experimental package.
c. A standard of spectral irradiance.
d. A standard mercury lamp.
e. A standard CO(4p) lamp.
f. An uncalibrated tungsten lamp, or a high intensity lamp.
g. Rotary table, with angular encoder.
h. Diffuse reflectance standard screen.
i. Neutral density filters, assorted.
j. The AFGL UV calibration facility.
k. Low pressure Hg(Ne) calibration lamp and power supply.

The two digital outputs of the experiment, the UV flux and the wavelength encoder, will be inputted into the GSE for storage and off-line data analysis.

PRECEDING EACH TEST, THE POWER TO THE EXPERIMENTAL PACKAGE, TO THE GSE, AND TO ALL THE PERIPHERAL INSTRUMENTS SHOULD BE TURNED "ON" FOR APPROXIMATELY TEN MINUTES TO STABILIZE THEIR OPERATION.

WHEN USING THE STANDARD OF SPECTRAL IRRADIANCE OR THE TUNGSTEN LAMP, OR ANY UV EMITTING LAMP, APPROPRIATE EYE PROTECTION SHOULD BE WORN.

7.2 Absolute Calibration

This procedure will lead to a measurement of the parameter, $\varepsilon_{abs}(\lambda)$, which relates the instrument output to the absolute number of photons entering the front aperture of the instrument.

7.2.1 Test Setup

Figure 7 shows the radiometric calibration geometry to be used in the range 2500-3300 Å range. The standard of spectral irradiance lamp is placed facing the high reflectance diffusing screen at the required distance and positioned orthoginally to the screen surface. The instrument package is placed adjacent to the source so that its optical axis is as perpendicular to the screen as possible. The instrument package is shielded from any direct radiation from the standard lamp by an opaque screen. The spectrometer's fields-of-view are filled with the irradiated screen.

The whole assembly shall be located in the laboratory such that the distance to the nearest wall is large compared to the reference distance. The spectrometer's field-of-view is filled with the irradiated screen.

The radiation intensity is controlled by varying the distance from the standard lamp to the diffusing screen. Since there are no reliable data for the efficiency of the instrument in the 2500-3300 Å region, we calculate an upper limit for the number of photo-electrons out, and we find that the spectrometer most likely will have to be farther away than the standard distance from the screen, but less than 5 meters.

7.2.2 Data Taking

The standard of spectral irradiance is turned "ON" and allowed to stabilize (for a time TBD). The current through the lamp is set at the manufacturer's recommended value. With the grating mirror scanning, the digital outputs of the spectrometer are recorded by the GSE and stored. The measurement shall be conducted over a ten minute period. During that time, approximately ten data sets, spaced evenly in time, shall be recorded.

For the absolute calibration of the spectrometer below 2500 Å, the AFGL UV Facility will be used. First, a measurement shall be made to normalize the calibration results obtained at Visidyne, in the 2500-3300 Å range, with those

in the same range done at AFGL. For this purpose, a rare gas standard is used. The AFGL standard calibration procedures for the setup of the spectrometer in the test chamber will be followed.

With the grating mirror scanning, the digital outputs of the spectrometer are recorded by the GSE and stored. The values of the output signals, taken over a time interval of ten minutes, shall be recorded.

At the shorter wavelengths the Hg and CO(4P) lamp sources possess severe astigmatism, and for this reason they are limited to sources having dimensions 10 inches in length and 6 mm in width (full width half maximum). The light flux from these sources will not fill the whole aperture of the instrument. A rectangular aperture shall be built with a width of 12 mm and positioned in front of the entrance aperture of the spectrometer oriented with the large dimension of this rectangular aperture in line with the long dimension of the source.

A normalization measurement of this rectangular aperture must first be done. For this, rare gase standard lamp is again used. Following the preceding test, and without disturbing the configuration of the spectrometer inside the chamber, the rectangular aperture is now placed in front of its entrance aperture and the preceding measurement is repeated. From these two measurements performed over the same wavelengths, the precise area of the rectangular collimator is calculated.

With the rectangular aperture in place, the absolute calibration of the instrument, in the range of 2000-3000 Å, is performed, using the Hg standard lamp.

With the rectangular aperture in place, the absolute calibration of the instrument, in the 1300-2000 Å range is done, using the CO(4P) standard lamp.

7.3 Noise Level

The noise level of the instrument is measured with the front aperture of the instrument covered with an appropriate light-tight cover and with the room in total darkness. Under these conditions, the digital output of the detector is recorded by the GSE and stored. Several readings of the noise level over a one-hour interval shall be recorded. Care should be taken to suppress any stray light sources in the room.

7.4 Linearity and Dynamic Range

The purpose of this test is to determine the dynamic range of the instrument, and the range over which its response is linear in the region 2500 Å to 3300 Å. The result from this test will be a curve of the instrument counting rate versus the luminous flux entering the system.

7.4.1 Experimental Setup

The instrument is directed facing an uncalibrated tungsten filament lamp or some other high intensity lamp two or three meters away, as shown in Figure 9. The current through the lamp is increased until saturation or near saturation of the output of the PMT occurs. Time should be allowed for the lamp to stabilize.

7.4.2 Data Taking

Under the above conditions, the output from the instrument is recorded. Without changing the current through the lamp, several (as many as ten) neutral density filters of various optical densities are placed in front of the light source, and the different outputs of the PMT corresponding to the known absorption recorded.

Since the lamp intensity can drift, it is important to check its stability as the series of measurements progresses. To infer the stability of the lamp, an intensity normalization point shall be chosen in the linear portion of the response curve of the instrument. This intensity is obtained by interposing a fixed amount of absorption in the light beam. Following each recorded data point, and before more absorption is introduced in the beam, the intensity of the lamp shall be checked at the normalization point and adjusted if necessary. This procedure is repeated until the noise level of the instrument is reached, and the desired curve is obtained.

If the entire dynamic range of the instrument cannot be covered with the previous lamp setting and using all the availability filters the intensity of the lamp shall be reduced to the intensity used to normalize the different measurements but without the filters. With this new lamp intensity, the original data taking procedure is repeated, until the noise level of the system is reached.

7.5 Wavelength Calibration and Scan Linearity

The wavelength calibration of the ultraviolet spectrometer will be performed using a low pressure Hg(Ne) calibration lamp. This lamp will be powered by a high-frequency, square-wave power supply designed for calibration

equipment. The Hg lamp has strong well known emission lines from 1849 Å to 5461 Å. The 1849 Å transition is a strong emission line that can be observed by flooding the instrument with nitrogen thus flushing out any oxygen. (For wavelengths shorter than 1849 Å the AFGL UV Calibration Facility will be used.) These emission lines will be used to fit the wavelengths with their respective encoder positions. Table 3 is a list of the emission lines from the different sources. The power supply frequency for the Hg lamp is 25 kHz, which is much higher than the sampling frequency (750 Hz), eliminating any oscillations in intensity caused by the lamp power supply. The power supply current is subject to variations of 0.1 percent.

The encoder signal, which is proportional to the angular displacement of the spectrometer grating, is recorded concurrently with the spectral response from the lamps. The encoder position is plotted versus sample number; the result is expected to be linear. The constants derived from the encoder calibration are combined with the fit of the emission line wavelengths versus sample number resulting in the relationship between the wavelength and the encoder position.

In addition to the wavelength calibration, the peak shape of the emission lines will be fit to determine the resolution of the instrument. The spectrometer has a built-in low pressure Hg(Ne) lamp which will be used to monitor the positions and shapes of a few strong emission lines after the instrument has been calibrated.

As part of the spectral response measurement, the attenuator disk efficiency will be obtained. This efficiency will be calculated by measuring the attenuation of the different lines emitted by the calibration lamp as a disk rotates in front of the entrance slit.

7.6 Field-of-View Mapping

This experiment measures the instrument response as a function of the angle of the incident light. All angles are measured with respect to the instrument optical axis. The resulting data will be displayed as a plot of the incident light intensity versus angular displacement both in the horizontal and vertical directions.

7.6.1 Test Setup

The experimental setup is shown in Figure 6. The instrument is positioned on a rotary table with its orthogonal axes of rotation intersecting the optical center of the focusing lens of the instrument.

An uncalibrated tungsten light source is positioned as shown in the figure so that its image is focused by a converging lens at the focal point of a parabolic mirror. The instrument is located in the beam of parallel rays from the source. Care must be taken that the entire aperture of the instrument be filled by the light from the source.

7.6.2 Data Taking

The instrument is rotated in the horizontal plane so that a maximum output signal is generated. This is the "zero" angular displacement reference. The instrument is rotated until the output signal is close to or at the instrument noise level. The angular position of the instrument at this extreme is recorded. The angular position of the instrument is now stepped up toward the zero angular reference and pass this point until the output signal is again near or at the instrument noise level. This angular span is divided in a number of equal angular intervals. (The nominal angular size of the aperture being 0.075°, there should be at least five intervals). At each of these angular positions, the output signal amplitude is recorded. To eliminate the backlash of the rotating table, the direction of rotation should always be in the same direction. The preceding procedure is repeated after each horizontal scan the spectrometer is rotated one degree in the vertical direction until the source image is off the entrance slit.

The spectrometer is then rotated in the opposite vertical direction past the original angular position by an amount equal to the nominal field-of-view. Starting from this new position in elevation, the angular scans are performed, each time after having changed the elevation of the optical axis of the instrument by one degree toward the original position.

An additional angular scan, using the CO(4P) lamp in the AFGL Calibration Facility, will be performed. The spectrometer is orientated in the chamber so that the long axis of its slit is horizontal. The entrance slit is scanned in angular steps TBD.

8. X-RAY DETECTORS

The following equipment is needed to calibrate the X-ray Detectors:

a. The EXCEDE GSE.

b. The experimental package.

c. Various X-ray sources.

d. Helium environment.

e. A precision pulser.

The three digital outputs of the experiment, which consist of two data channels and a Pulse Height Analyzer (PHA) encoding (energy) channel, will be inputted to the GSE for storage and off-line data analysis.

8.1 Preparation

The experimental package will be placed in a helium environment. A large bag filled with helium will house the x-ray detector and any x-ray sources.

8.2 Absolute Efficiency

The absolute efficiency of the detectors will be provided by theoretical efficiency curves of the detectors. These curves are obtained from physical and geometrical considerations of the detectors. The efficiency prediction at 5.9 keV will be verified using a Fe-55 source.

8.3 Pulse Centroid, Shape, and Linearity

8.3.1 Test Setup

The x-ray sources are positioned at various points in front of the counter to measure the pulse centroids and pulse shapes. The X-kit targets and Fe-55 source provide five x-ray lines from 1.2 to 5.9 keV.

8.3.2 Data Taking

The PHA is allowed to accumulate a spectrum for each position in front of the detectors. Approximately 10,000 counts in the center channel of the photo-peak from the spectrum are needed. The spectrum shall be stored on disk for analysis of the centroid and line shape. This procedure is repeated for each of the five sources.

Next, the linearity and dynamic range of the PHA is measured. A precision pulse is used to generate pulses with rise-time and decay-time constants set at 0.05 μs and 100 μs, respectively. Pulses are injected, in turn, in the front

end of the pre-amps. The amplitude of these pulses should correspond to the same energy channel as the centroid of the 5.898 keV photo-peak in each of the two PHA's. The pulse amplitudes are decreased until they coincide with the lower thresholds of the first energy channels in each of the PHA's and their values recorded. The amplitudes are then increased to coincide with the upper energy thresholds of the 128th channel in each of the PHA's and their values recorded. The range should correspond to 0 to 6 keV. The pulse amplitudes are again reduced to their lower energy threshold values and incremented in ten equally-spaced increments toward the upper energy boundaries of the PHA's to measure the PHA linearity. Following each increment, the corresponding channel numbers are recorded.

8.4 Field-of-View Mapping

No field-of-view mapping will be performed. Instead, the nominal field-of view of 8° x 8° will be used in the data analysis.

8.5 Resulting Data

At the end of the test, the following data shall be available:

a) PHA linearity, small counter.

b) PHA linearity, large counter.

c) Five energy spectra, small counter.

d) Five energy spectra, large counter.

These data shall be stored on disk or magnetic tape for later analysis and reference.

9. RETARDING POTENTIAL ANALYZER (RPA)

9.1 Preparation

The following equipment are needed:

a. The EXCEDE Analog GSE

b. The Experimental Package

c. The Visidyne Vacuum Chamber

d. CRT Electron Gun

The three digital outputs from the instrument, which consist of two data channels, V^{Log}_{det} and V^{lin}_{det}, and a retarding potential and off-line analysis.

The electron source for these measurements is a CRT electron gun which covers 30-110 eV; the complete energy range of the RPA is 0-110 eV.

The RPA is mounted inside the Visidyne vacuum chamber; all connections for the instrument or the gun will be provided through four ports in the side of the chamber.

Test Set-Up

The electron gun will be mounted as close to the RPA as possible (~ 1.5 inches). The detector will be mounted on a rigid post inside the chamber; a Faraday cup will be mounted on this same post. The post can be raised or lowered to position either the RPA or the Faraday Cup in the beam path. The apertures of both instruments lie on the axis of rotation of the post and can be rotated +/-50° with respect to the beam direction.

The RPA is connected to an amplifier whose response is logarithmic for photomultiplier currents between 10^{-9} and 10^{-3} A, and linear between 5×10^{-4} and 5×10^{-2} A. The lowest current threshold of 10^{-9} corresponds to an electron flux of 6.24×10^{9} electrons/second detected at the cathode. The area of the entrance aperture is 0.317 cm^2, and the transmission for the grid system is estimated to be ≈ 80%; the minimum detectable beam flux is ≈ 2.5×10^{10} electrons/cm^2.

9.2 Field of View

The RPA is axially symmetric with respect to the beam axis, and therefore as a minimum it is sufficient to map only one angular direction. The instrument response is not only a function of angle but also of energy. The angular response will be measured at three energies: 40, 75, and 105 eV. At each energy the field of view will be sampled in 10 degree intervals.

The result is the function $g(E,\Theta)$. No directional information will be available during the flight, therefore, the function will be integrated over the solid angle of the instrument.

$$G(E) = \Sigma\, g(E,\Theta)\, \Delta\Theta$$

9.3 Energy Calibration

With the RPA orthogonal to the beam, its energy response will be measured in the energy range 0-110 eV, in intervals of 20 eV. The energy resolution of the instrument will also be calculated from these data. The resulting function is $E(V_{monitor})$.

9.4 Absolute Calibration (Transmission)

A Faraday cup with a 0.25 inch (same as the RPA) aperture will be placed orthogonal to the beam at the position of the RPA and the current density of the beam will be measured. The beam current will be measured at five energies: 30, 40, 60, 80 and 100 eV. The RPA will then be placed in the beam and the current will be recorded at the same energies. The effective transmission of the RPA is then

$$\varepsilon(E)_{trans} = I(E)_{rpa}/I(E)_{beam}$$

9.5 Dynamic Range and Linearity

Because the full dynamic range of the detector is not completely covered by the gun, a calibrated current source (a resistor and a voltage source) will be placed in contact with the RPA cathode and the detector output will be recorded until saturation (at the high end) or noise (at the low end) is observed. The results will be a table of the form:

$$I_{source} = I(V_{det})$$

10. ELECTROSTATIC ANALYZER (ESA)

10.1 Preparation

The following equipment are needed.

a. The EXCEDE GSE

b. The Experimental Package

c. The Visidyne Vacuum Chamber

d. CRT Electron Gun

The two digital outputs from the instruments, which consist of a single data channel, V^{log}_{det}, and a sweep voltage monitor V_{sweep} channel, will be inputted to the GSE for storage and off-line analysis.

Electrons having energies in the range 100 to 3000 eV will be generated by a CRT electron gun. The complete energy range of the ESA is 100-6000 eV.

The ESA is mounted inside the Visidyne vacuum chamber; all connections for the instrument or the gun will be provided through four ports in the side of the chamber.

Test Set-Up

The CRT electron gun will be mounted on a port that can be rotated $\pm$ 50° with respect to the ESA. The ESA will be mounted in the rear of the chamber and will be stationary. Next to the instrument will be a Faraday Cup with a 0.25 inch aperture. The gun will be positioned so that the beam can be rotated from the ESA onto the Faraday Cup.

The ESA is connected to an amplifier whose response is logarithmic for photomultiplier currents between 10^{-9} and 10^{-3} A. The lowest current threshold of 10^{-9} corresponds to an electron flux of 6.24×10^{9} electrons/second detected at the cathode. The area of the entrance aperture is 1.47 cm^2 therefore the minimum detectable beam flux is $\simeq 4.25 \times 10^{9}$ electrons/cm^2.

10.2 Field of View

The field of view of the instrument will be determined by construction and the calculations will be checked against measurements from a previously built ESA. (The design of this instrument is similar to that of the previous ESA. The difference between the two is a Faraday Cup is being used to measure the electron current instead of a photomultiplier tube.)

The result is the function $g(\Theta,\phi)$. No directional information will be available during the flight, therefore, the function will be integrated over the solid angle of the instrument.

$$G(E) = \Sigma\, g(E,\Theta,\phi)\; \Delta\Theta\; \Delta\phi$$

10.3 Energy Calibration

With the ESA mounted orthogonal to the beam, its energy response will be measured in the energy range 100-6000 eV. The energy resolution of the instrument will also be calculated from these data. The resulting function is $E(V_{monitor})$.

10.4 Absolute Calibration (Transmission)

The transmission of the ESA will be determined from theoretical calculations and previous experience. These predictions will be confirmed with laboratory measurements. The Faraday Cup will be placed orthogonal to the beam at the position of the ESA and the current density of the beam will be measured. The beam current will be measured at several energies between 100 and 6000 eV. The ESA will then be placed in the beam and the current will be recorded at the same energies. The effective transmission of the ESA is then

$$\varepsilon(E)_{trans} = I\ (E)_{ESA}/I(E)_{beam}$$

10.5 Dynamic Range and Linearity

Because the full dynamic range of the detector is not completely covered by the gun, a calibrated current source (a resistor and a voltage source) will be placed in contact with the cathode and the detector output will be recorded until saturation (at the high end) or noise (at the low end) is observed. The results will be a table of the form:

$$I_{source} = I(V_{det})$$

TABLE 1. SUMMARY OF OPTICAL INSTRUMENT CALIBRATIONS

INSTRUMENT	SPECTROMETERS		FIXED PHOTOMETERS		SCANNING PHOTOMETERS				BORESIGHT PHOTOMETER
TEST	VISIBLE	UV	5200Å	5228Å	2761Å	3804Å	3914Å	5577Å	3914Å(2)
ABSOLUTE CALIBRATION	X	X	X	X	X	X	X	X	X
NOISE LEVEL	X	X	X	X	X	X	X	X	X
LINEARITY & DYNAMIC RANGE	X	X	X	X	X	X	X	X	X
SPECTRAL RESOLUTION	X	X	t	t	t	t	t	t	t
WAVELENGTH CALIBRATION	X	X							
SCAN LINEARITY					X	X	X	X	
OFF-AXIS REJECTION			X	X	X	X	X	X	
FOV MAPPING	X	X	X	X	X	X	X	X	X

t; Use manufacturer's calibration curves, and post-recovery calibration, if possible.

Table 2
Spectrometer Calibration Summary

PRODUCTION RATE OF PHOTO-ELECTRONS

$$P = (I)\ (\lambda/hc)\ (A\Omega/\pi)\ (\Delta\lambda)\ (Q.E.)\ (\Pi T_i)\ (\alpha) \tag{1}$$

where:

P	is the number of photo-electrons produced per second.
I	is the irradiance from the standard lamp corrected, if necessary, for its distance to the reflecting screen if different from the standard distance, in W/cm^2-nm.
λ/hc	is the conversion factor at the given wavelength λ, in photons/(s-W).
$A\Omega$	is the geometrical factor of the instrument, in cm^2-sr.
$\Delta\lambda$	is the instrument resolution, in nm.
Q.E.	is the quantum efficiency of the photocathode.
ΠT_i	is the product of the transmissions of the various optical elements.
α	is the scattering coefficient of the screen.

CALIBRATION FLUX

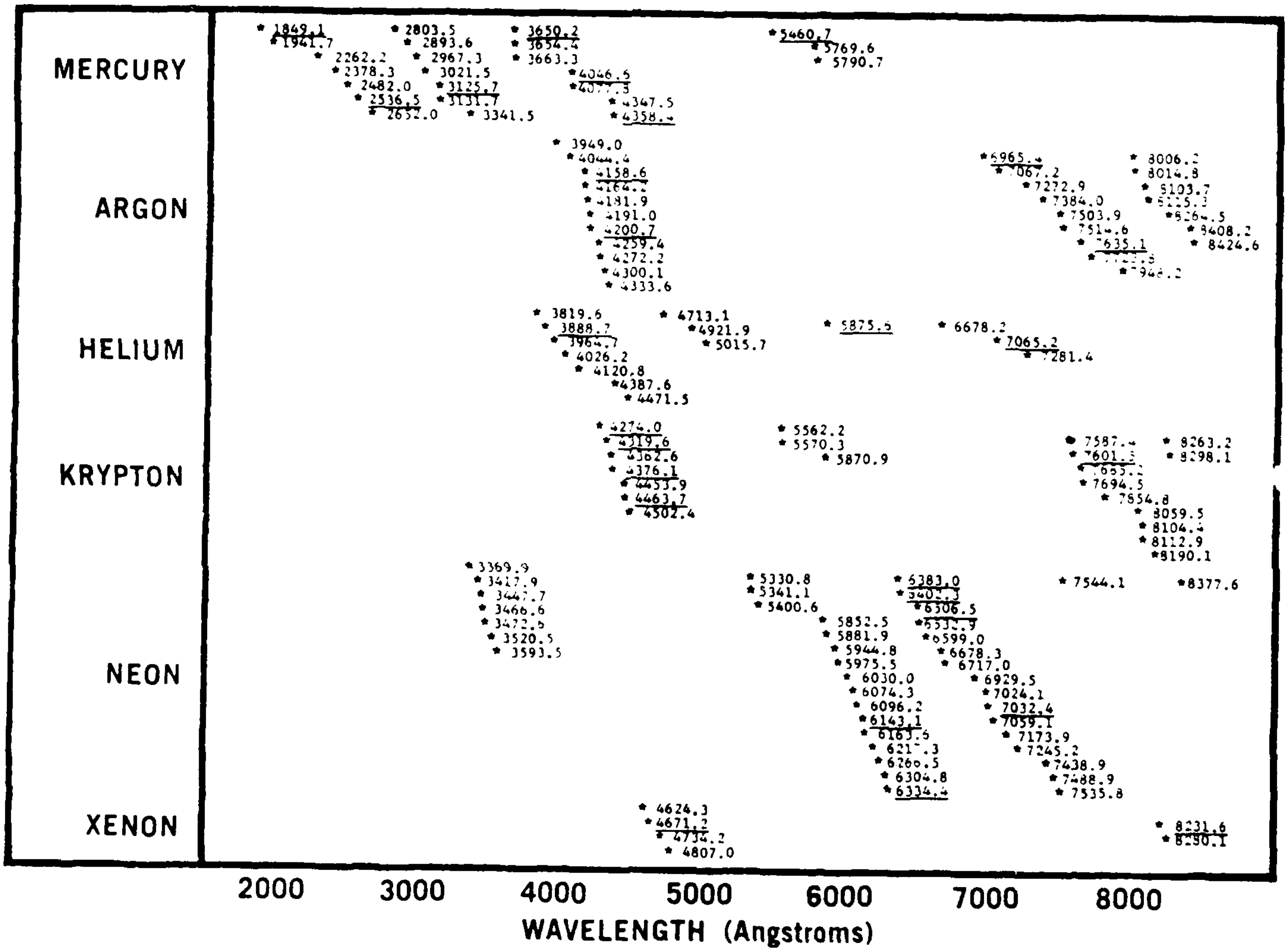
$$N = I(\lambda/hc)(A\Omega/\pi)(\Delta\lambda)\alpha \tag{2}$$

where:

N	is the number of photons per second incident on the entrance aperture and within the acceptance angle of the instrument.

Table 3

Calibration Lamp Emission Lines



(Underscored Numbers Indicate High Intensity Lines)

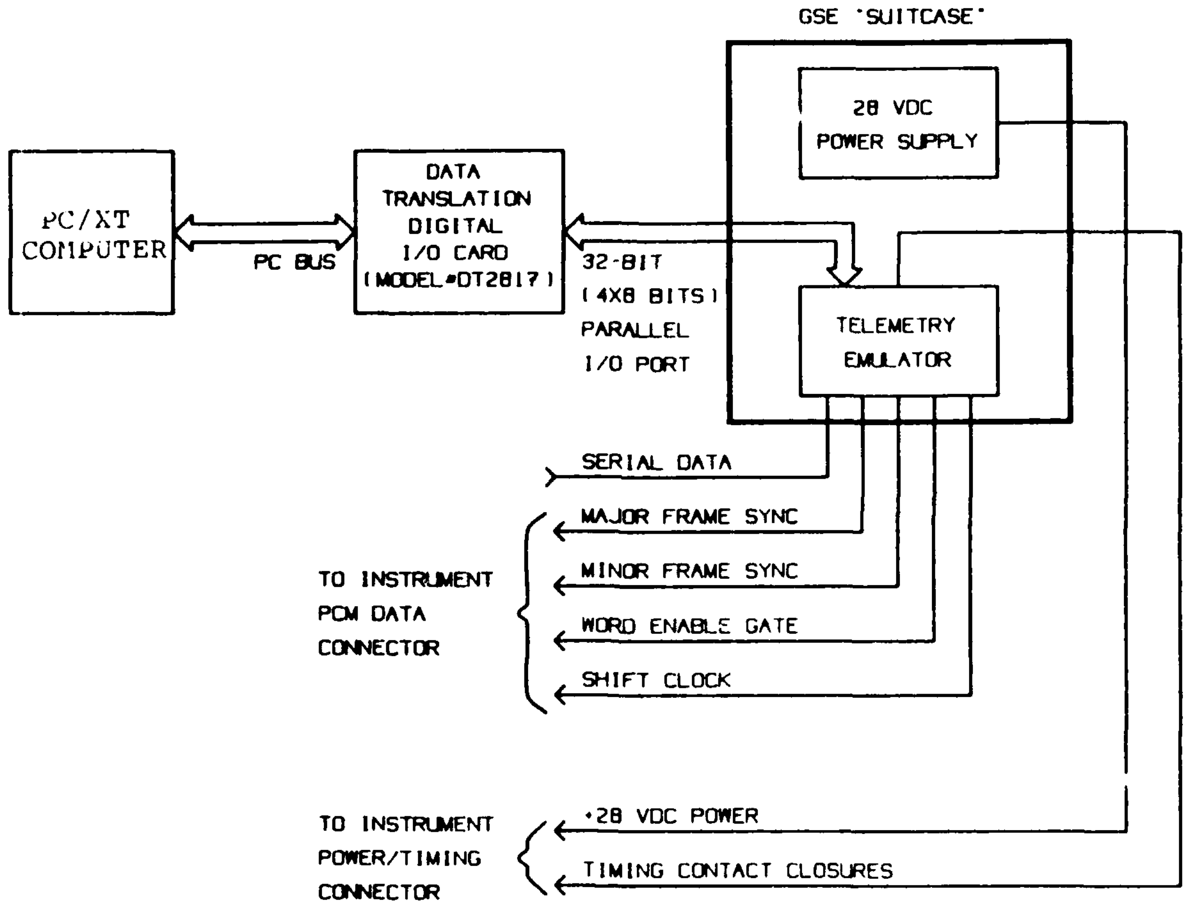


Figure 1. Block Diagram of the GSE for Serial Digital Instruments

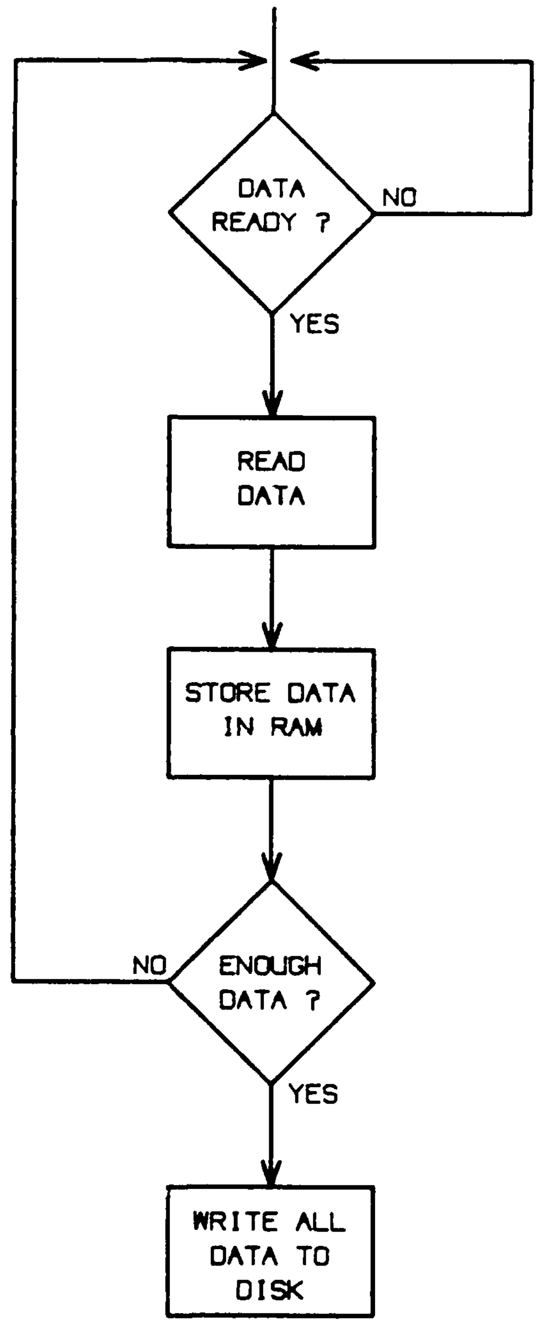


Figure 2. Flow Diagram of the GSE Software

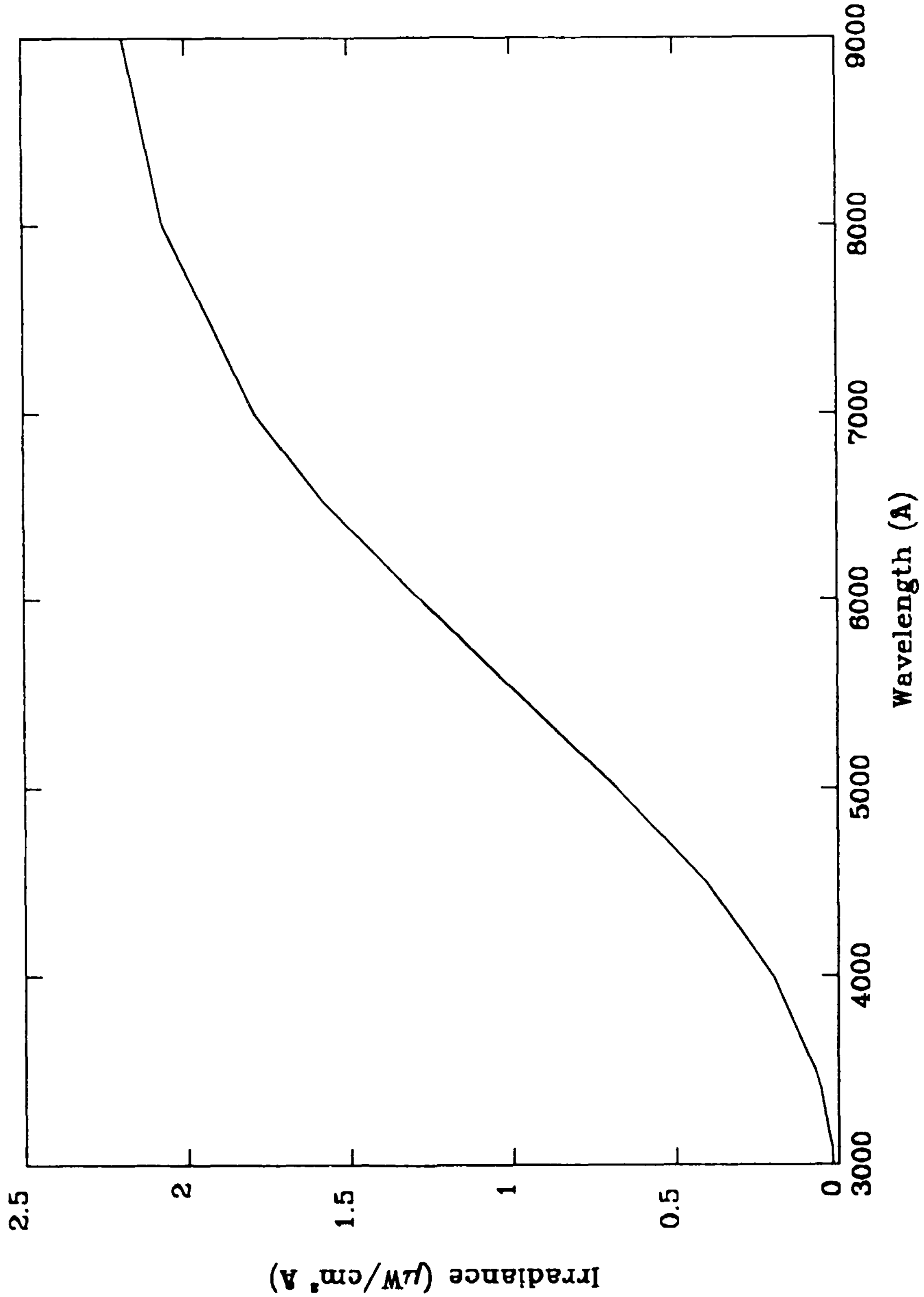


Figure 3. Spectral irradiance versus wavelength for a 1000 watts, G.E. type FEL lamp standard.

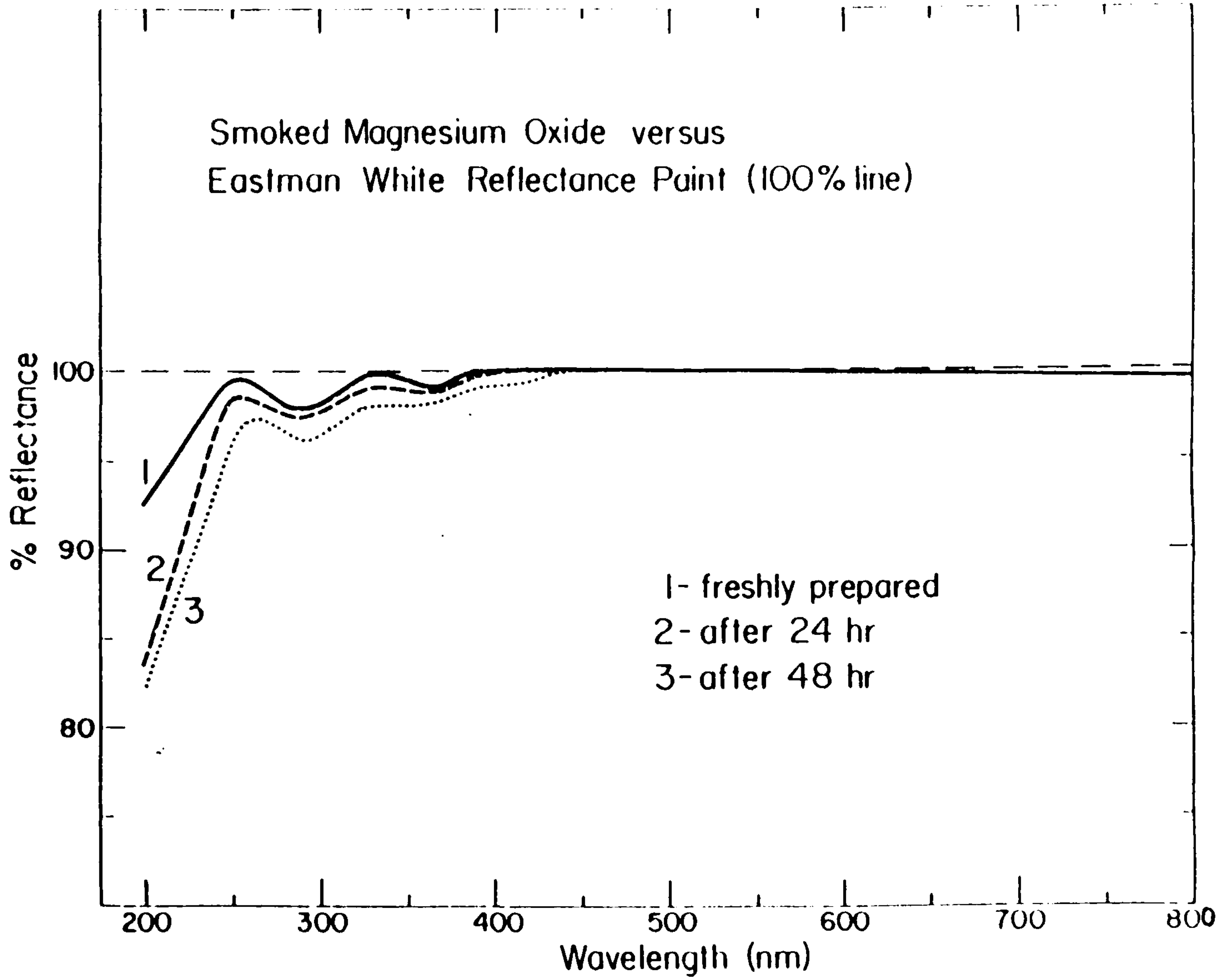


Figure 4. Percent reflectance versus wavelength for the diffuse reflectance standard screen

AFGL UV CALIBRATION FACILITY

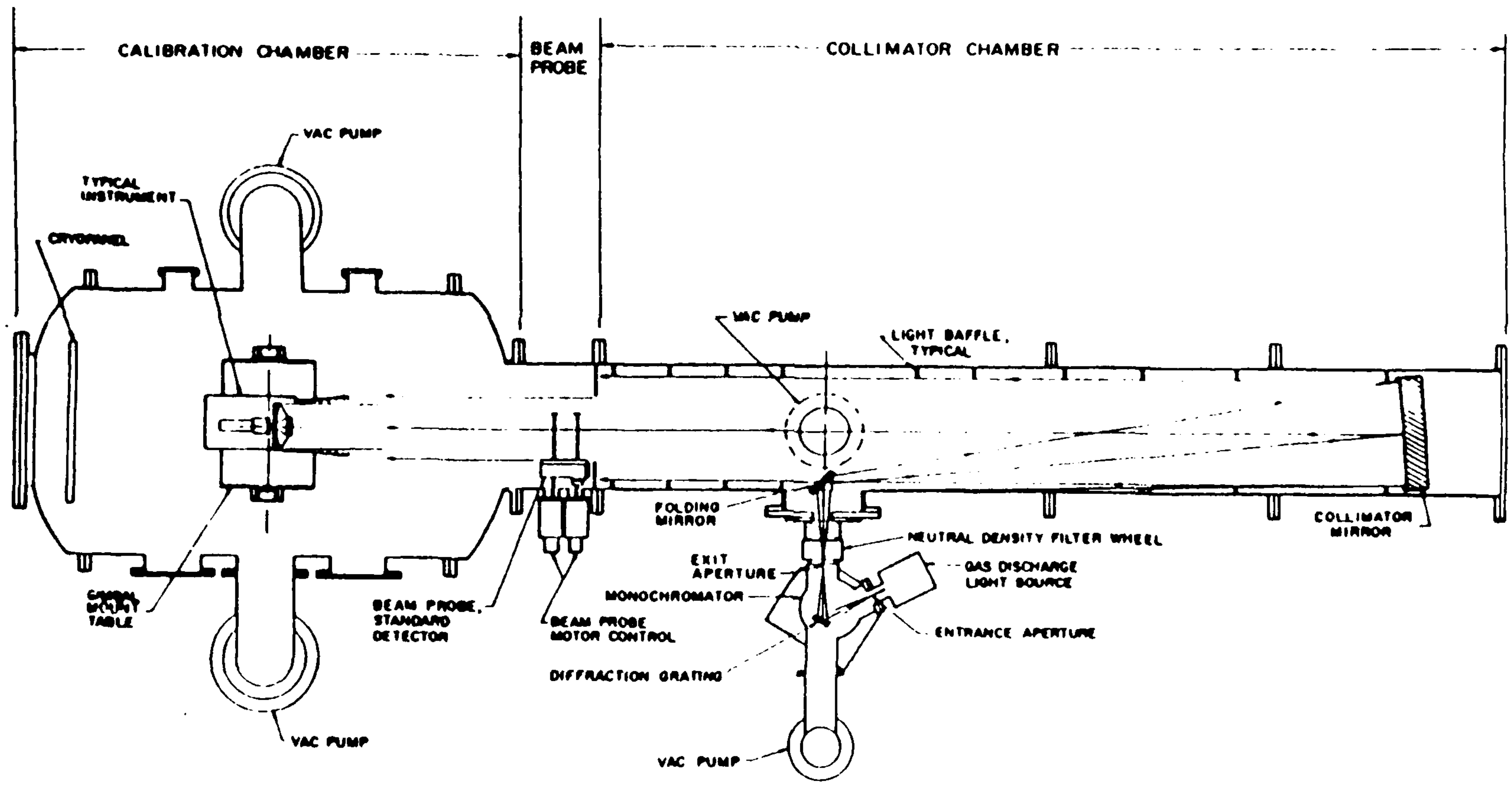


Figure 5. AFGL UV calibration facility

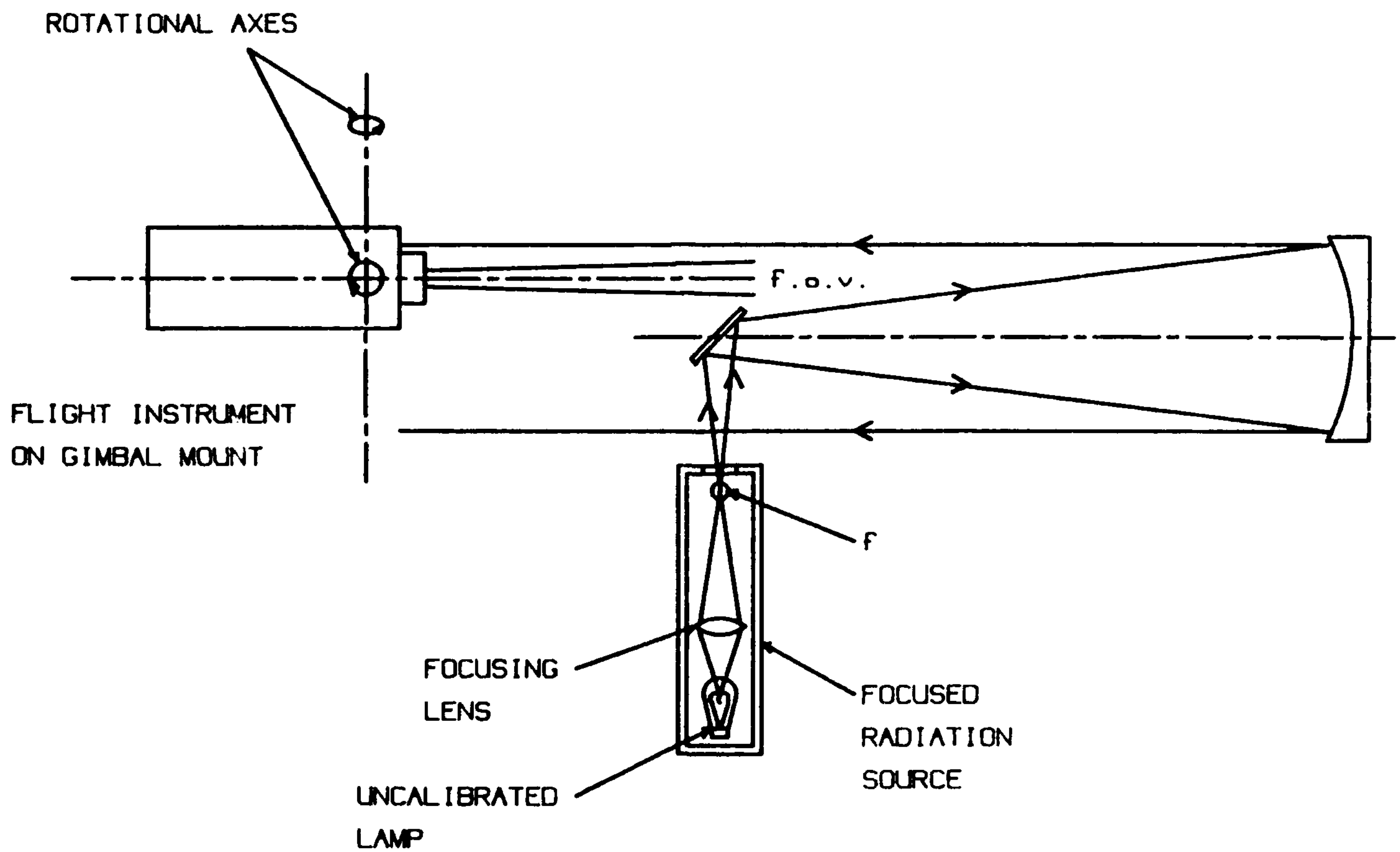


Figure 6. Field-of-view Mapping Geometry

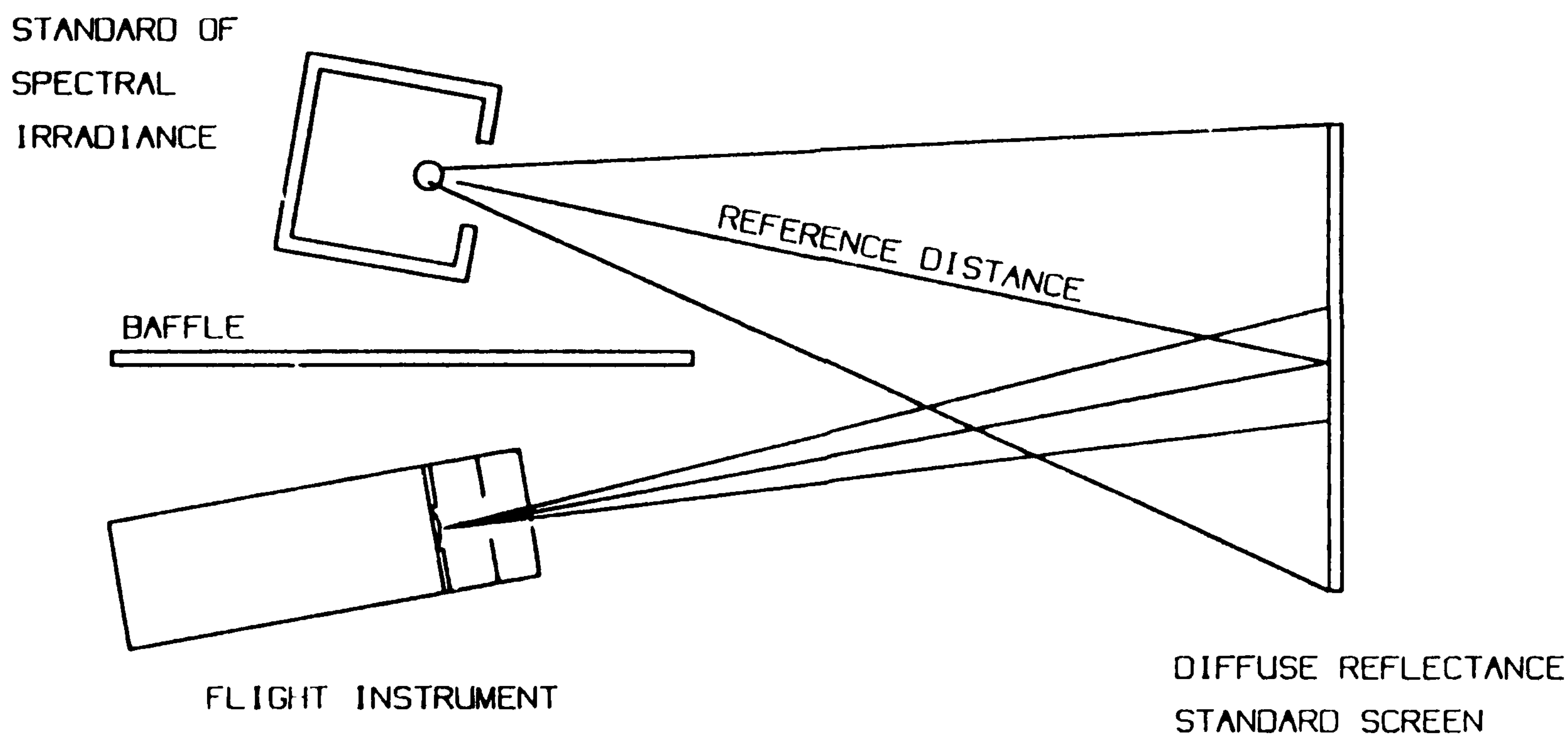


Figure 7. Radiometric calibration geometry

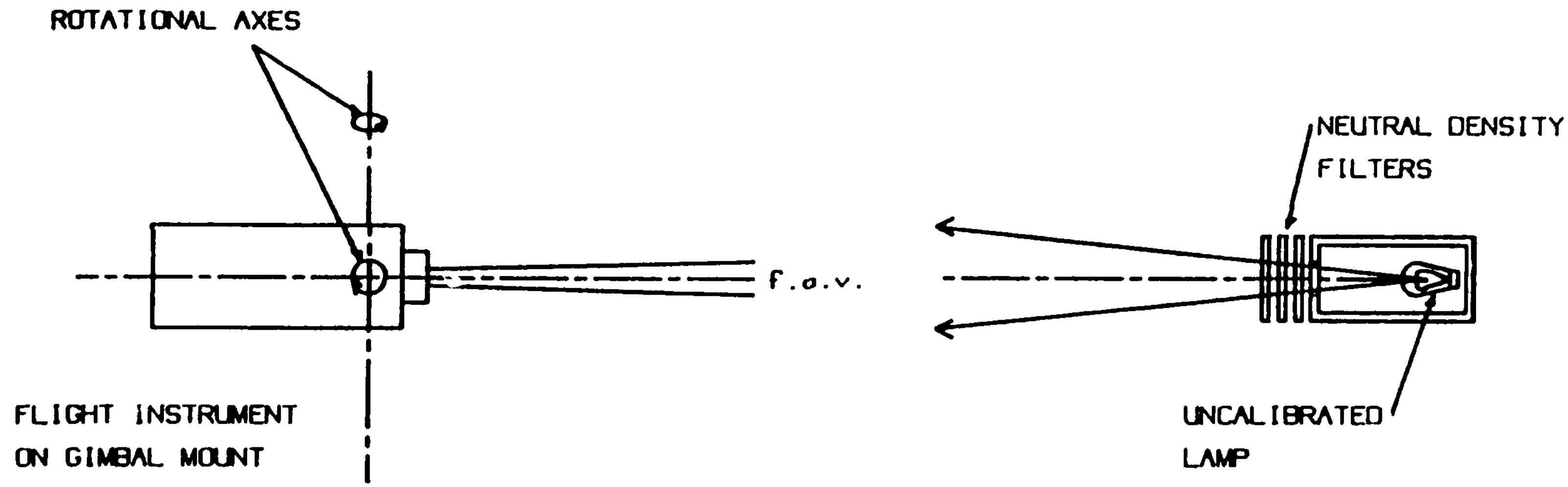


Figure 8. Linearity, dynamic range and off-axis rejection measurement geometry